Synopsis

With the age of hypersonic flight imminent just beyond the horizon, researchers are working hard at designing work-arounds for all the major problems as well as the minor quirks associated with it. One such issue, seemingly innocuous but one that could be potentially deadly, is the problem of interference heating due to surface protuberances. Although an ideal design of the external surfaces of a high-speed aircraft dictates complete smoothness to reduce drag, this is not always possible in reality. Control surfaces, sheet joints, cable protection pads etc. generate surface discontinuities of varying geometries, in the form of both protrusions as well as cavities. These discontinuities are most often small in dimension, comparable to the local boundary layer thickness at that location. Such protuberances always experience high rates of heat transfer, and therefore should be appropriately shielded. However, thermal shielding of the protrusions alone is not a full solution to the problem at hand. The interference caused to the boundary layer by the flow causes the generation of local hot spots in the vicinity of the protuberances, which should be properly mapped and adequately addressed. The work presented in this thesis aims at locating and measuring the heat flux values at these hot spots near the protrusions, and possibly formulating empirical correlations to predict the hot spot heat flux for a given set of flow conditions and protrusion geometry.

Experimental investigations were conducted on a flat plate model and a cone model, with interchangeable sharp and blunt nose tips, with attached 3D protuberances. Platinum thin-film sensors were placed around the protrusion so that the heat fluxes could be measured in its vicinity and the hottest spot located. These experiments were carried out at five different hypersonic freestream flow conditions generated using two shock tunnels, one of the conventional type, and the other of the free-piston driven type. The geometry of the protrusions, i.e., the height and the deflection angle, was also parametrically varied to study its effect on the hot spot heat flux. The results thus obtained for the flat plate case were compared to existing correlations in the open literature from a similar previous study at a much higher Reynolds number range. Since a mismatch was observed between the results of the current experiments and the existing correlations, a new empirical correlation has been developed to predict the hot spot heat flux, that is valid within the range of flow conditions studied here. A similar attempt was made for the case of the cone model, for which no previous correlations exist in the open literature. However, a global correlation covering the entire range of flow conditions used here could not be formed. A correlation that is valid for just one out of the five flow conditions used here is presented for the cones with sharp and blunt nose tips separately.

Schlieren flow visualization was carried out to obtain a better understanding of the shock structures near the protuberances on both models. For most cases, where the protrusion height and deflection angle were large enough to cause flow separation immediately upstream of the protuberance, a separation shock was manifested which deflected some part of the boundary layer above the protuberance, while the rest of the fluid in the boundary layer entered a recirculating region in the separated zone before escaping to the side. Some preliminary computational analysis was conducted which confirmed this qualitatively. However, the quantitative match of surface heat flux between the simulations and experiments were not encouraging. Schlieren visualization revealed that for the flat plate case, the foot of the separation shock was located at a distance of 10.5 to 12 times the protrusion height ahead of it, whereas in the case of the sharp cone, it was at a distance of 9 to 10.5 times the protrusion height. The unsteady nature of the separation shock was also captured and addressed. Some preliminary experiments on boundary layer tripping were also conducted, the results of which have been presented here.

From this analysis, it has become evident that a single global correlation cannot be formed which could be used for a wide range of flow conditions to predict the hot spot heat flux in interference interactions. The entire range of conditions that may be encountered during hypersonic flight has to be broken down into sections, and the interference heating pattern should be studied in each of these sections individually. By doing so, a series of different correlations can be formed at the varying flow conditions which will then be available for high-speed aircraft designers.